Title

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When Nominal Features are marked on Verbs: A Transcranial Magnetic Stimulation Study

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Abstract

It has often been claimed that verb processing (as opposed to noun processing) is subserved by specific neural circuits in the left prefrontal cortex. In this study, we took advantage of the unusual grammatical characteristics of clitic pronouns in Italian (e.g., *lo* and *la* in *portalo* and *portala* 'bring it [masculine]/[feminine]' respectively) – the fact that clitics have both nominal and verbal characteristics to explore the neural correlates of verb processing. We used repetitive transcranial magnetic stimulation (rTMS) to suppress the excitability of left prefrontal cortex and to assess its role in producing verb+det+noun and verb+clitic phrases. Results showed an interference effect for both kinds of phrases when stimulation was applied to the left but not the as right prefrontal cortex. However, the interference effect was significantly greater for the verb+clitic than for the verb+det+noun phrases. These findings suggest that clitics increase the morphological complexity of verbs, thus supporting the view that they are treated as affix-like elements.

Introduction

Increasing interest in the neural basis of grammatical class has led to converging evidence that nouns and verbs are subserved by distinct neural mechanisms. Neuropsychological reports on brain-damaged subjects have shown that nouns and verbs can be selectively impaired (Caramazza & Hillis, 1991; Damasio & Tranel, 1993; Berndt & Haendiges, 2000; Shapiro, Shelton, & Caramazza, 2000), thus setting the stage for a thorough investigation with new methodologies. Electrophysiological studies of verb and noun perception show increased left-lateralized anterior positivity for verbs (Dehaene, 1995; Federmeier, Segal, Lombrozo, & Kutas, 2000). Studies using positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) have demonstrated that left prefrontal and medial frontal cortex are recruited in verb processing tasks (Raichle, Fiez, Videen, MacLeod, Pardo, Fox, & Petersen, 1994; Petersen, Fox, Posner, Mintum, & Raichle, 1988; 1989; Perani, Cappa, Schnur, Tettamanti, Collina, Rosa, & Fazio, 1999).

Repetitive transcranial magnetic stimulation (rTMS) has also been used to show that morphosyntactic operations on verbs can be selectively impaired (Shapiro, Pascual-Leone, Mottaghy, Gangitano, & Caramazza, 2001). One of the major advantages of the rTMS technique is that it demonstrates not only that a brain region is active during the performance of a given task but that the area is actually necessary for the task being performed (Walsh & Rushworth, 1999). When applied at low frequency (1 Hz), rTMS temporarily interferes with cognitive processing beyond the duration of a train of pulses (Pascual-Leone, Walsh, & Rothwell, 2000).

Shapiro et al. (2001) found that, following rTMS targeted to a portion of the left prefrontal cortex along the midfrontal gyrus anterior and superior to Broca's area, both verb and pseudo-verb production were significantly impaired, whereas noun and pseudo-noun production were unaffected.

The participants' task was to produce singular or plural noun forms and 3rd person singular or plural verb forms in response to specific cues. The fact that the morphological operation always involved the same kind of phonological material (add or subtract /s/ as in *a car/some cars*, *they jump/he jumps*), ruled out any explanation in terms of phonological differences between verbs and nouns. Furthermore, the fact that the same pattern of results was obtained for real words and pseudo-words suggests that the left prefrontal cortex is sensitive to the grammatical properties of nouns and verbs independently of other conceptual-semantic properties that may be correlated with words of different grammatical classes.

The objective of the current study was to extend the research on the neural correlates of grammatical category to a special class of pronouns, widespread in Romance languages, called clitics (e.g., in Italian, *lo* and *la* in *portalo* and *portala* 'bring it [masculine]/[feminine]' respectively). Although clitics have nominal referents and are specified for nominal features (e.g., gender), they attach to verbs and depend phonologically and syntactically on verbs.

Italian clitics can precede (i.e., they are proclitics) or follow (i.e., they are enclitics) the verb (cf. *lo porto* 'I bring him/it' vs. *portalo* 'bring him/it [you]'), depending on the verb form. In enclisis, the clitic and the verb are combined into one word, with the clitic forming a kind of affix. In this study, only enclitic object forms were used (e.g., *portalo* 'bring him/it [you]'. See Finocchiaro & Caramazza, in press).

Because of their nominal properties, clitics require conceptual-semantic and grammatical information about their noun referents (e.g., gender, number, and case features). Because of their connection to verbs, at some processing stage they must be combined with the verb. However, the formation of the verb-clitic cluster may be localized at different levels: morphological (e.g., Crysmann, 2000; Monachesi, 1999) or phrasal (i.e., syntactic, e.g., Kayne, 1991; Uriagereka, 1995; Belletti, 1999).

The lexicalist view holds that clitics are affix-like elements. Therefore, the verb-clitic relation is exactly parallel to the verbal base-verbal affix relation, in that neither clitics nor verbal affixes are supposed to fill an argument position. Instead, both of them would attach to the verb in the lexicon. The syntactic approach assumes that the object clitic is generated in argument position. Then, according to one of the most influential analysis (e.g., Kayne 1991), the clitic left-adjoins to a functional head, yielding the clitic-Verb order in cases where the functional head dominates the verb. (The Verb-clitic order in Italian is thought to result from the verb's having moved leftward past the functional head to which the clitic has adjoined). As already noted, the main objective of this study was to determine whether the circuits dedicated to verb processing are also involved in processing the clitics that attach to them. Thus, we used low-frequency rTMS in order to transiently disrupt the normal functioning of the same portion of the left prefrontal cortex targeted in Shapiro et al. (2001).

The syntactic account of clitic formation predicts no difference between verb+det+noun and verb+clitic phrases after rTMS disruption. This is because the syntactic relation between a verb and its direct object is independent from the grammatical category of the object itself (noun, pronoun). On the other hand, the morphological account predicts that the presence of a clitic would increase the morphological complexity of the verb, thus increasing – exactly like a verbal affix - the involvement of the brain region devoted to verb morphology.

In the present experiment, we tested participants before and after left and right rTMS on a task that required the production of verb+det+noun or verb+clitic phrases.

To anticipate the results, it was found that left rTMS – as opposed to right rTMS - interfered with the production of both phrase types; however, the magnitude of interference was significantly stronger for verb+clitic than verb+det+noun phrases.

Methods

Materials

Ninety black-and-white pictures of objects were selected: fifty pictures for the experimental task; forty for the control task (see the Appendix). Picture names were controlled for length and frequency as reported in the Corpus di Italiano Contemporaneo (1988). For the experimental task, mean picture name frequency was 68, mean letter length was 6.1, mean syllable length was 2.6. For the naming task, mean frequency was 56, mean letter length was 7; mean syllable length was 2.7. Twelve additional pictures were used as practice trials at the beginning of the control task, and twenty at the beginning of the experimental task.

Five verbs were selected. Each verb was paired with ten pictures.

Stimulus presentation was randomized for each participant. Particular care was taken to avoid semantic, phonological, or associative relations between consecutive trials.

Procedure

Each subject participated in two sessions separated by at least one week. In the first session, rTMS was applied to the targeted area to only one hemisphere and to the other hemisphere in the second session. The procedure for each session was the same: participants were first familiarized with all the pictures; they then named a set of 40 control pictures both before and after rTMS application. They rested for half an hour, and then did the experimental phrase production task before and after another rTMS application.

During the picture familiarization phase, pictures were presented one at a time. For each item, a fixation cross first appeared for 500 ms, followed by a picture for 2000 ms, with the object's name appearing beneath the picture for the final 1500 ms. Participants were asked to name the picture aloud upon seeing its name. The next trial initiated after 800 ms.

During the next part of the experiment, participants named control pictures without word prompts. Twelve practice trials preceded the set. For each item, a fixation cross appeared for 500 ms and was immediately followed by the picture. The participant was to name the picture, which would immediately disappear. The inter-trial interval was fixed at 2000 ms.

After one block of picture naming, 600 pulses of 1Hz rTMS were applied to the left or right hemisphere of the participant, and the naming task was repeated.

Participants then rested for half an hour, after which they began the phrase production task. Twenty practice trials preceded the experimental trials. For each trial, a fixation cross appeared on the screen for 500 ms, followed by the infinitive form of a verb (e.g., *guardare* 'to look at') for 250 ms, and then a picture of an object. Participants were instructed to inflect the verb in the second person singular of the imperative (e.g., *guarda* 'look at') and, depending on the experimental condition, to follow it with either the appropriate object clitic pronoun (*lo* 'it' [m] or *la* 'it' [f]) or the appropriate determiner and noun (e.g., *guarda il tavolo* 'look at the table'). Verbs were presented in capital letters in 32-point Arial font. The inter-trial interval was fixed at 2500 ms.

Six hundred pulses of 1Hz rTMS were then applied to the same hemisphere stimulated for the naming task, and the phrase production task was repeated.

The same procedure was followed for both sessions for each participant, with rTMS applied in the second session to the hemisphere not stimulated in the first session. There was a minimum interval of 1 week between sessions.

Application of rTMS

Magnetic stimulation was delivered by a Cadwell high-frequency magnetic stimulator equipped with a water-cooled figure-of-eight coil (each loop 4.5 cm in diameter). In each experimental session, two trains of 600 pulses were delivered at 1Hz frequency and 100% of the motor threshold. Motor threshold (MT) was determined for each subject as the minimum stimulus intensity able to elicit in 5 or more of ten consecutive stimulations a motor evoked potential (MEP) of at least 50 uV in contralateral first dorsal interosseous.

The scalp position for stimulation in each subject was 6 cm anterior and 1 cm ventral to the motor spot for the first dorsal interosseous muscle. In the left hemisphere, this position targeted an inferior portion of the midfrontal gyrus just anterior and superior to Broca's area (see Shapiro et al. 2001). This position was marked on tightly fitting Lycra caps worn by subjects. The order of hemisphere stimulation was counterbalanced across participants.

Participants

Eleven right-handed native Italian speakers (ages 22-38) volunteered for the experiment. All participants were healthy and had no history of neurological or psychiatric illness. All participants gave their informed consent to the experiment, which was approved by a local ethics committee. Each participant was randomly assigned to group 1 (N = 6) or group 2 (N = 5). All participants performed the control task.

Statistical Analysis

The following were scored as errors and excluded from the main analysis: responses that differed from the targets, failures to respond, failures of recording equipment, RTs above 2000 ms and below 300 ms, and RTs exceeding each participant's mean by more than 3 s.d.

A repeated-measure ANOVA was performed on the reaction time differences (Δ) between pre-rTMS performance and post-rTMS performance for each hemisphere. The same procedure was followed for the experimental task and the control task.

There were two variables, each with two levels: Condition (verb+clitic *vs.* verb+det+noun), and Site (left *vs.* right). Condition was treated as a between-subjects variable; site was treated as a within-subject variable.

The same statistical analysis was performed with participants' errors as dependent measures.

Results

Experimental task

Discarded data accounted for 3.8% of the verb+clitic condition and for 4.8% of the verb+det+noun condition. No significant effects emerged from the error analysis.

Analysis of response latencies revealed a main effect of Site ($F(1,548) = 23$, $p < .001$), showing that subjects were slower after left rTMS than after right rTMS. There was also an interaction of Condition X Site ($F(1,548) = 4$, $p = .04$).

Duncan post-hoc analyses showed that the difference between right and left stimulation was significant for both the verb+clitic ($p < .001$) and the verb+det+noun conditions ($p < .05$). In addition, the reaction time differences (Δ) between pre-rTMS performance and post-rTMS performance were the same for both conditions when rTMS was delivered to the right hemisphere ($p = .9$), but not when rTMS was delivered to the left hemisphere ($p = .046$.). The latter finding shows that left rTMS – as opposed to right rTMS - significantly reduced the learning effect in both conditions. However, the magnitude of the interference was greater for the verb+clitic condition than the verb+det+noun condition (See Figure 1).

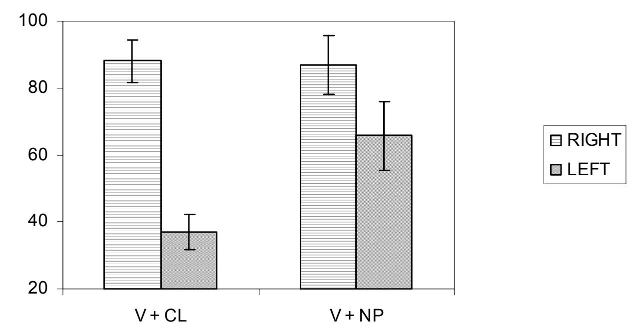

Figure 1: Effects of left and right rTMS on production of verb+clitic and verb+det+noun phrases. Error bars depict standard errors of the means.

Control task

Discarded data accounted for 5.1% of the verb+clitic condition and for 5.75% of the verb+det+noun condition. Error rates did not differ across conditions.

For RTs, the only significant effect was a main effect of Condition ($F(1, 438) = 6.5$, $P = .01$). This finding reflects the fact that, independently of site, participants in the verb+det+noun condition were significantly faster after the application of rTMS than participants in the verb+clitic condition (51.1 msec *vs.* 22.7 msec). However, the amount of facilitation was unaffected by the side of stimulation for both conditions (verb+clitic: 20.4 msec, SE 8 (right) *vs.* 25 msec, SE 8 (left); [verb+det+noun]: 45 msec, SE 11 (right) *vs.* 57 msec, SE 15 (left)).

Discussion

Our results support the view that the left prefrontal cortex plays a crucial role in processing a verb's morphology. It is well known that the repetition of production tasks with a limited set of stimuli causes a robust decrease in response latency over time. Our results show that rTMS applied to the left prefrontal cortex substantially reduces the magnitude of this learning effect for verb production. When people must name pictures (that is, when they have to produce nouns), there is no difference in effect between left and right rTMS.

Unlike Shapiro et al. (2001), verb morphology was not directly manipulated in this study. The same verb form was produced in every trial from the infinitive form. It is quite interesting that even such a simple morphological operation is sufficient to show selective involvement of the left prefrontal cortex in verb production.

This study is original in showing the differential effects of left rTMS on the production of verb+det+noun and verb+clitic phrases. After right rTMS, there is an equal amount of facilitation - due to the repetition of the task- in both conditions. After left rTMS, there is a significant reduction of this facilitation effect for both conditions. Crucially, however, this reduction is significantly greater for the verb+clitic than the verb+det+noun phrase condition. This finding can be attributed to the special status of clitics: although clitics have nominal referents, they are phonologically and syntactically dependent on the verb. This dependency is particularly strong in the case of enclitics, as they are orthographically attached to verbs. We conjecture that (en)clitics may increase the morphological complexity of the verb -- indeed, clitics seem to be treated as verbal affixes rather than as nominal particles.

Of course, this is not to deny the syntactic relationship clitic-verb. The hypothesis simply states that this syntactic relationship is not responsible for the differential patterns of rTMS effects found for the verb+clitic *vs.* verb+det+noun conditions, for otherwise the interference from left rTMS would be the same for verb+clitic and verb+det+noun phrases. This latter expectation derives from the fact that the syntactic relation between the verb and its object does not vary depending on the object's grammatical category – noun *vs.* pronoun.

Alternatively, one may want to appeal to a phonological explanation of the clitic results. According to this account, left rTMS could be disrupting the phonological processes associated with the verb-clitic integration. In this case, our results would not speak to the morphological aspects of cliticization. However, there is independent evidence that the left brain area stimulated in this study - the inferior portion of the midfrontal gyrus just anterior and superior to Broca's area - is more sensitive to morphosyntax than to phonology. Thus, Shapiro et al. (2001) found that the application of rTMS to this brain area interfered with verb and pseudo-verb production but not with noun and pseudo-noun production. Since their task always involved the same kind of phonological material (add or subtract /s/) independently of the grammatical class of the given stimulus, a phonological account of the results is not plausible. Hence, the most straightforward view seems to be that the effects of rTMS on clitic production do indeed reveal processing of the morphosynatx of verb-clitic clusters.

Another alternative explanation can be formulated in terms of differences in the semantic content of clitic phrases and noun phrases. In other words, it could be argued that the differential patterns of performance between the verb+clitic and verb+det+noun conditions reflect the different semantic content of clitics and nouns. Perhaps a fully specified noun engages a much more extensive neural network than a clitic. However, it must be noted that input conditions were the same for both the verb+clitic and verb+det+noun phrases. Participants had to extract the same type of semantic information from a given picture independently of the response format. Moreover, the information needed for the selection of of the grammatical features for the NP and the clitic is the same in the two cases. Thus, it is not clear how the same type of information could recruit different semantic neural networks depending on the specific condition.

These considerations receive additional support from those linguistic analyses that draw a parallel between the function of situationally salient definite NPs and deictic pronouns (e.g., von Heusinger, 2002). Accordingly, both clitics and NPs would be functionally equivalent in our experimental context, in that they both denote a contextually salient object (i.e., the pictured object) in the response to be produced. Note further that, even assuming a difference in semantic processing between clitics and NPs, it is not clear how this difference would be modulated by the application of rTMS to a given brain area. Our results could also be compatible with a syntactic account based on grammatical class differences between nouns and pronouns. On this view, the pattern of effects observed here should be attributed to processing differences between grammatical categories (pronouns *versus* nouns) rather than to differences in verb processing. The reasoning would be that the neural substrates for pronoun and verb processing overlap more than the neural substrates for noun and verb processing. Although this hypothesis cannot be dismissed, it must be noted that clitic production was compared to determiner + noun production, and not to bare noun production. Crucially, clitics – as well as the corresponding strong pronouns - and articles both require grammatical information about the noun's number and gender. There is no principled reason to believe that these properties are retrieved from different neural structures for pronouns *versus* articles. Therefore, until independent evidence is available on the neural correlates of grammatical classes other than nouns and verbs, the most straightforward interpretation of our data is that the differential impact of left rTMS on the production of verb+clitic and verb+det+noun phrases is to be attributed to the peculiar morphological relation between verb and clitic rather than to the clitics' grammatical class (pronoun).

Follow-up research with similar experimental designs as the one used here could help discriminate between the grammatical category and the morphological accounts. For example, it would be interesting to compare the behavior of strong pronouns (e.g., demonstratives such as *questo/questa* 'this [mas.]/this [fem.]' and *quello/quella* 'that [mas.]/that [fem.]') with enclitics. According to the grammatical class account, demonstratives should pattern with enclitics as they are both members of the class of pronouns. On the other hand, according to the morphological account, demonstratives should pattern differently from enclitics, since they do not form a morphological unit with the verb as is the case for enclitics. However,predictions regarding the behavior of demonstrative pronouns can only be tentative since they appear to be semantically different from third person pronouns. For instance, it has been argued (e.g., Bhat, 2004) that whereas the identification of third person pronouns – as well as the identification of NPs – only require pragmatic (i.e., linguistic) information, the identification of demonstratives and other proforms requires a more substantial (i.e., semantic) identification.

A different but related question concerns the behaviour of proclitics (e.g., clitics that do not orthographically attach to verbs, as in *lo guardo* 'I look at it'). The predictions of the grammatical class account are the same as for demonstratives: on the assumption that all types of pronouns behave the same, the behavior of enclitics and proclitics is expected to be the same. The predictions derived from then morphological account are not clear and depend on how the well known asymmetries between enclitics and proclitics are interpreted. Specifically, the morphosyntactic relation between the proclitic and the host verb appears to be less strong than the relation between the enclitic and the host verb (Benincà & Cinque 1993). Thus, according to the morphological account, expectations on proclitics crucially depend on their supposed status – morphological affixes or free morphemes. In the first case, they would pattern with enclitics, whereas in the second case they would pattern with noun phrases.

Conclusions

Our results extend in an important way the research on the neural correlates of grammatical class. We have shown that when nominal features attach to verbs, they are processed, in part, by the same neural circuits that are involved in processing verb morphology.

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Authors' notes

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Appendix

Materials to be used in the experiment

Experimental task

Feminine Pictures

banana 'banana', macchina 'car', pistola 'gun', tenda 'tent', zucca 'pumpkin', chiesa 'church', farfalla 'butterfly', piramide 'pyramid', sirena 'siren', tromba 'trumpet', chitarra 'guitar', croce 'cross', ruota 'wheel', sedia 'chair', sella 'saddle', carota 'carrot', chiave 'key', mucca 'cow', racchetta 'racket', scala 'ladder', foca 'seal', giraffa 'giraffe', pera 'pear', scarpa 'shoe', scopa 'broom'

Masculine Pictures

giornale 'newspaper', letto 'bed', libro 'book', rossetto 'lipstick', serpente 'snake', albero 'tree', calendario 'calendar', dado 'dice', orologio 'watch', sole 'sun', anello 'ring', birillo 'skittle', carciofo 'artichoke', cubo 'cube', imbuto 'funnel', cappello 'hat', fungo 'mushroom', osso 'bone', timone 'helm', topo 'mouse', leone 'lion', ombrello 'umbrella', pettine 'comb', piatto 'plate', scheletro 'skeleton'

Verbs

comprare 'to buy', guardare 'to look at', portare 'to bring', prendere 'to take', trovare 'to find'

Control task

Feminine Pictures

carriola 'wheelchair', ciliegia 'cherry', lumaca 'snail', siringa 'syringe', scimmia 'monkey', spazzola 'brush', sciarpa 'scarf', matita 'pencil', panchina 'bench', tigre 'tiger', ballerina 'dancer', maschera 'mask', gabbia 'cage', spada 'sword', colonna 'column', porta 'door', bomba 'bomb', pipa 'pipe', pianta 'plant', campana 'bell'

Masculine Pictures

vaso 'vase', fucile 'rifle', disco 'disc', coltello 'knife', telefono 'telephone', piede 'foot', treno 'train', braccio 'arm', occhio 'eye', pinguino 'penguin', tagliere 'chopping board', tubo 'tube', portafoglio 'wallet', ananas 'pineapple', biberon 'feeding bottle', semaforo 'traffic-light', aquilone 'kite', tamburo 'drum', lucchetto 'padlock', ventaglio 'fan'